Direct Photons at RHIC

– Results from PHENIX –

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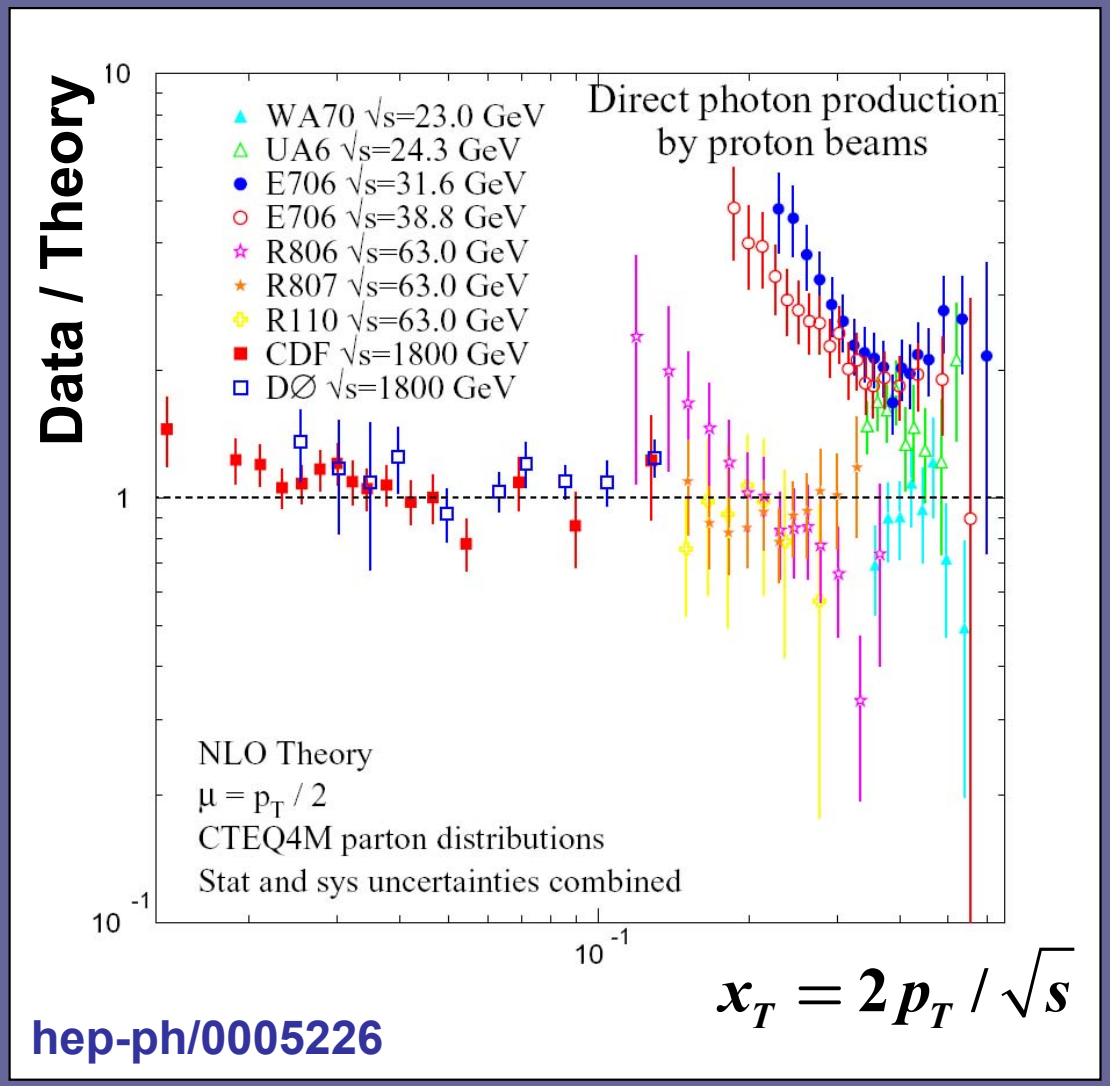
Direct Photons in p+p Collisions – Why?

1. Test of QCD
   - Photon directly from interaction of pointlike partons, no complication due to parton→hadron fragmentation
2. Information about gluon distribution in the proton (especially interesting for fractional momenta $x_{Bjorken} > 0.1$)
   - Gluon involved at leading order (LO) in Quark-Gluon Compton scattering ($q+g \rightarrow q+\gamma$)
   - This is in contrast to deeply inelastic scattering and Drell-Yan where gluon is involved only at NLO
   - However, γ data not generally used in global QCD fits!!
3. Baseline for direct photon measurements in A+A collisions

Experimental Challenge: Background from $\pi^0 \rightarrow \gamma + \gamma$, $\eta \rightarrow \gamma + \gamma$

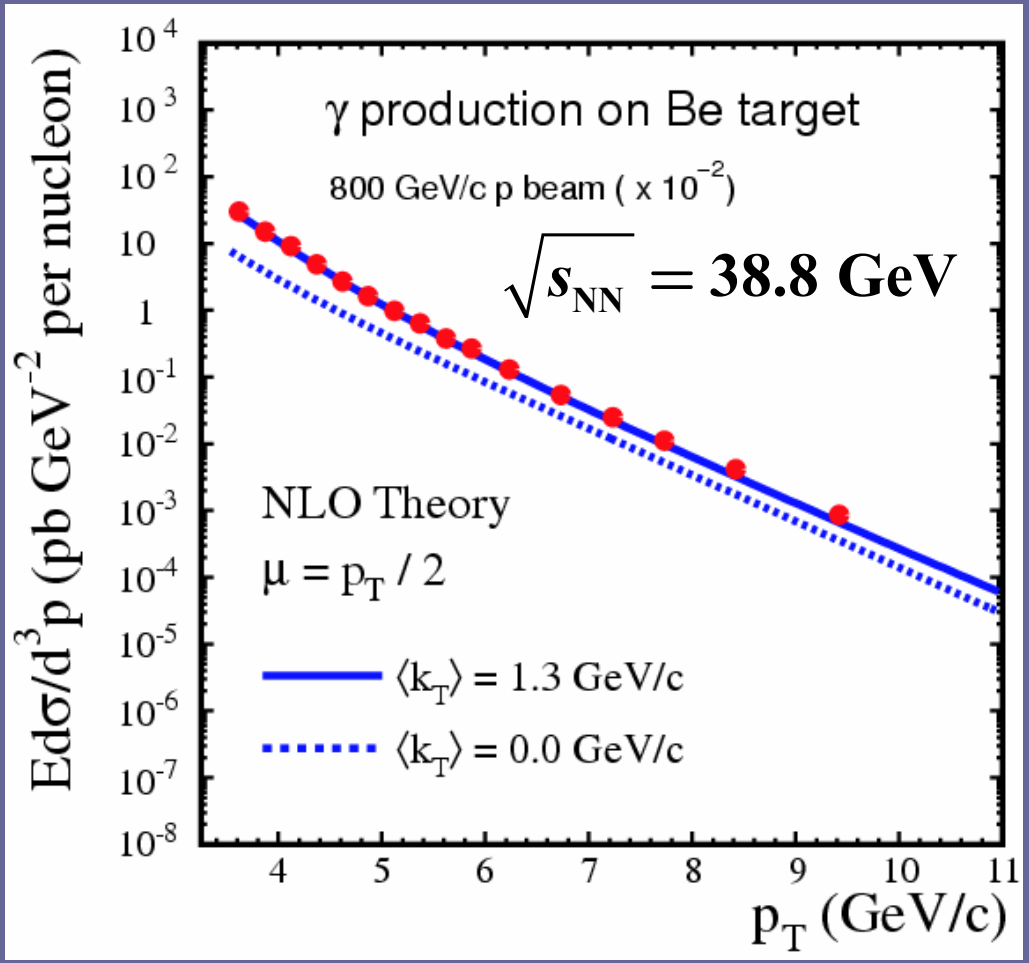
p+p($\bar{p}$) Direct Photon Data and pQCD – What's the Status?



- Decent agreement at large √s
- Substantial deviations between data and NLO pQCD at small √s
- Questions:
  - Is there a systematic pattern of deviation?
  - If so, can the introduction of additional transverse momentum (k_T) of initial partons improve the agreement?
  - Are the data sets mutually consistent?

Need new measurements to solve the puzzle

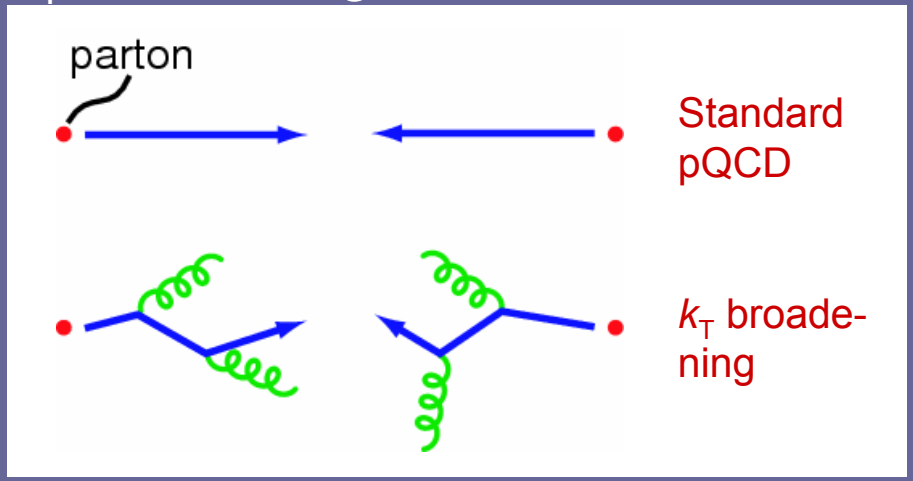
Evidence for k_T Broadening



E706, Phys.Rev.D70:092009,2004

- Data from E706 fixed target experiment can be explained with $\langle k_T \rangle \approx 1.3$ GeV/c

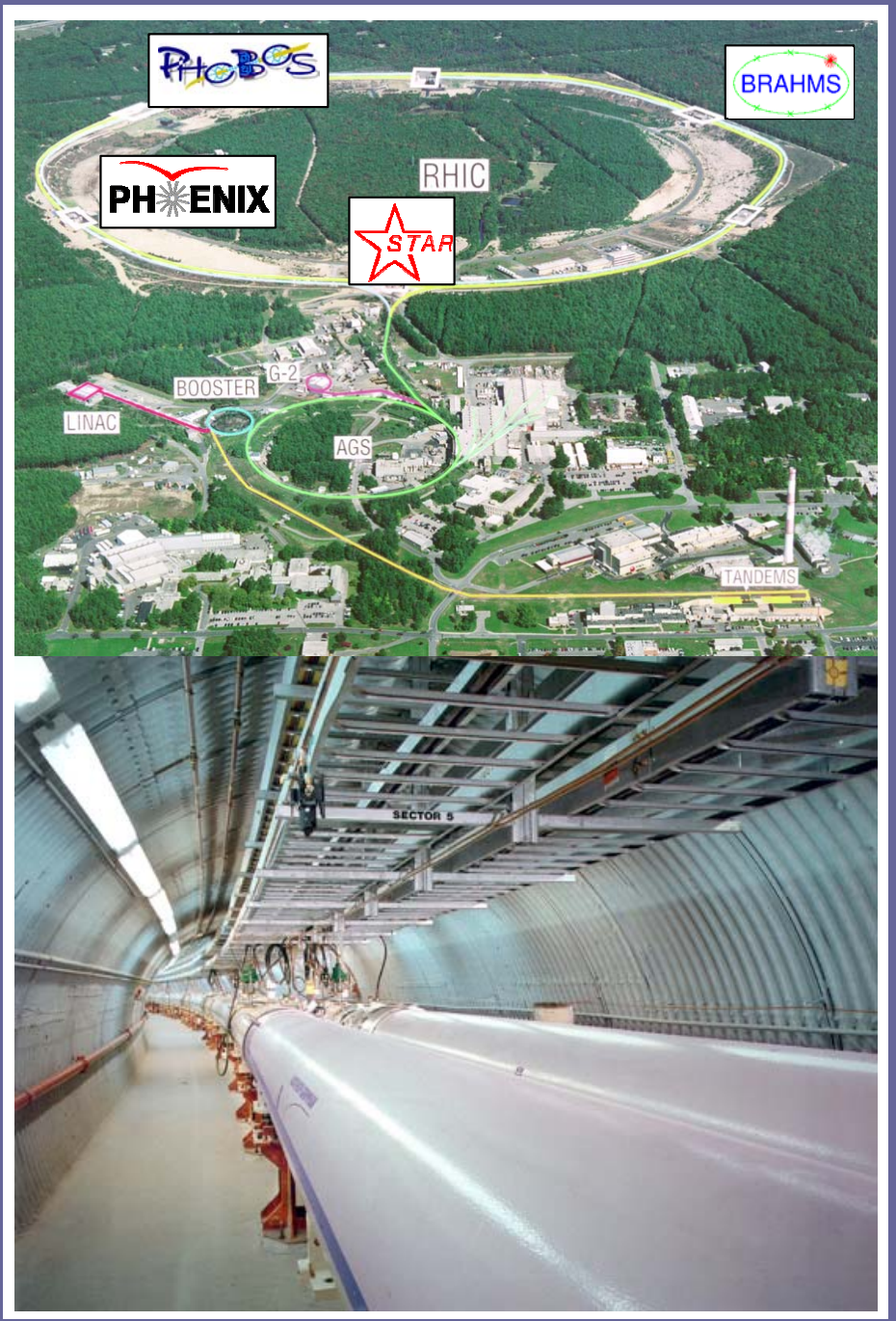
k_T broadening:



Is there evidence for k_T broadening in p+p at $\sqrt{s}$ = 200 GeV ?

RHIC: Relativistic Heavy Ion Collider

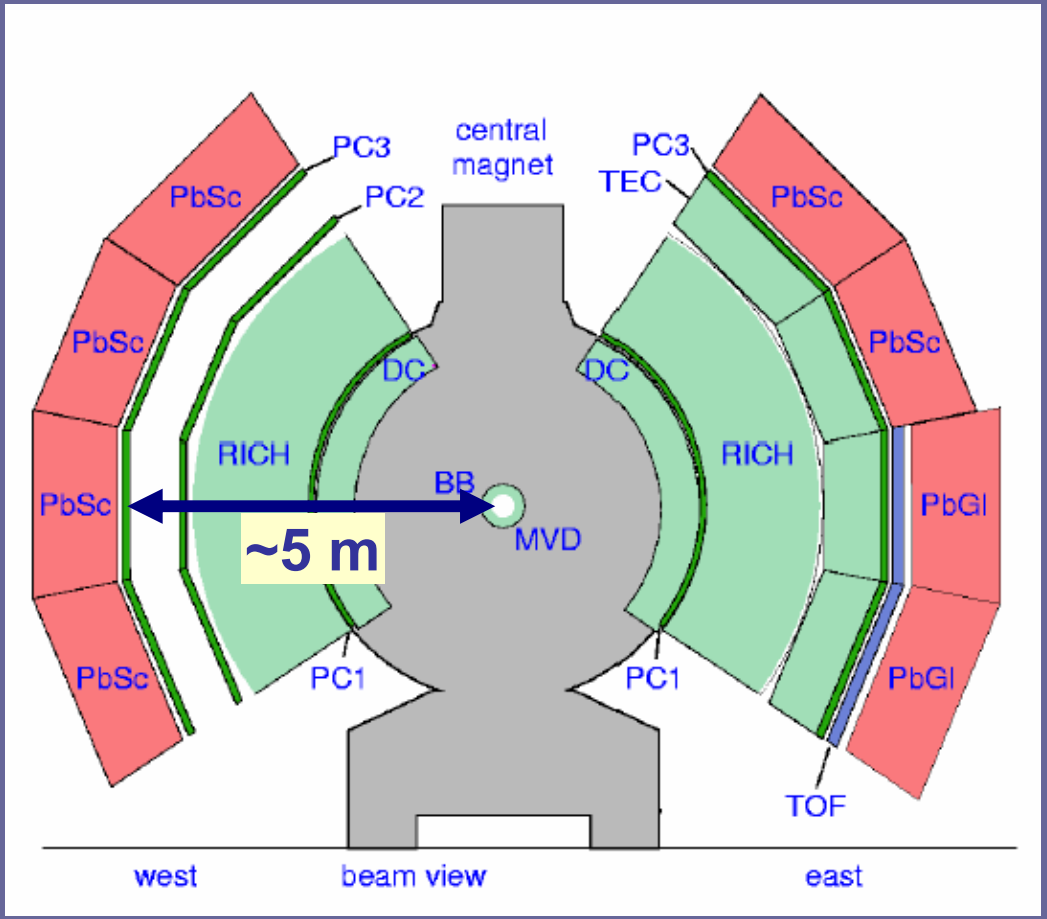
- 2 independent rings
  - circumference 3.8 km
  - 6 intersection, 4 experiments
- Any nucleus on any other, polarized p+p collisions
- Luminosities:
  - Au+Au: $2 \times 10^{26}\ \mathrm{cm^{-2}s^{-1}}$
  - p+p: $1.4 \times 10^{31}\ \mathrm{cm^{-2}s^{-1}}$



Focus of this talk:
p+p direct photon data from Run-3 (2003)

$$\sqrt{s} = 200\ \mathrm{GeV}, \int L\,dt = 266\,\mathrm{nb}^{-1}$$

The PHENIX Electromagnetic Calorimeter

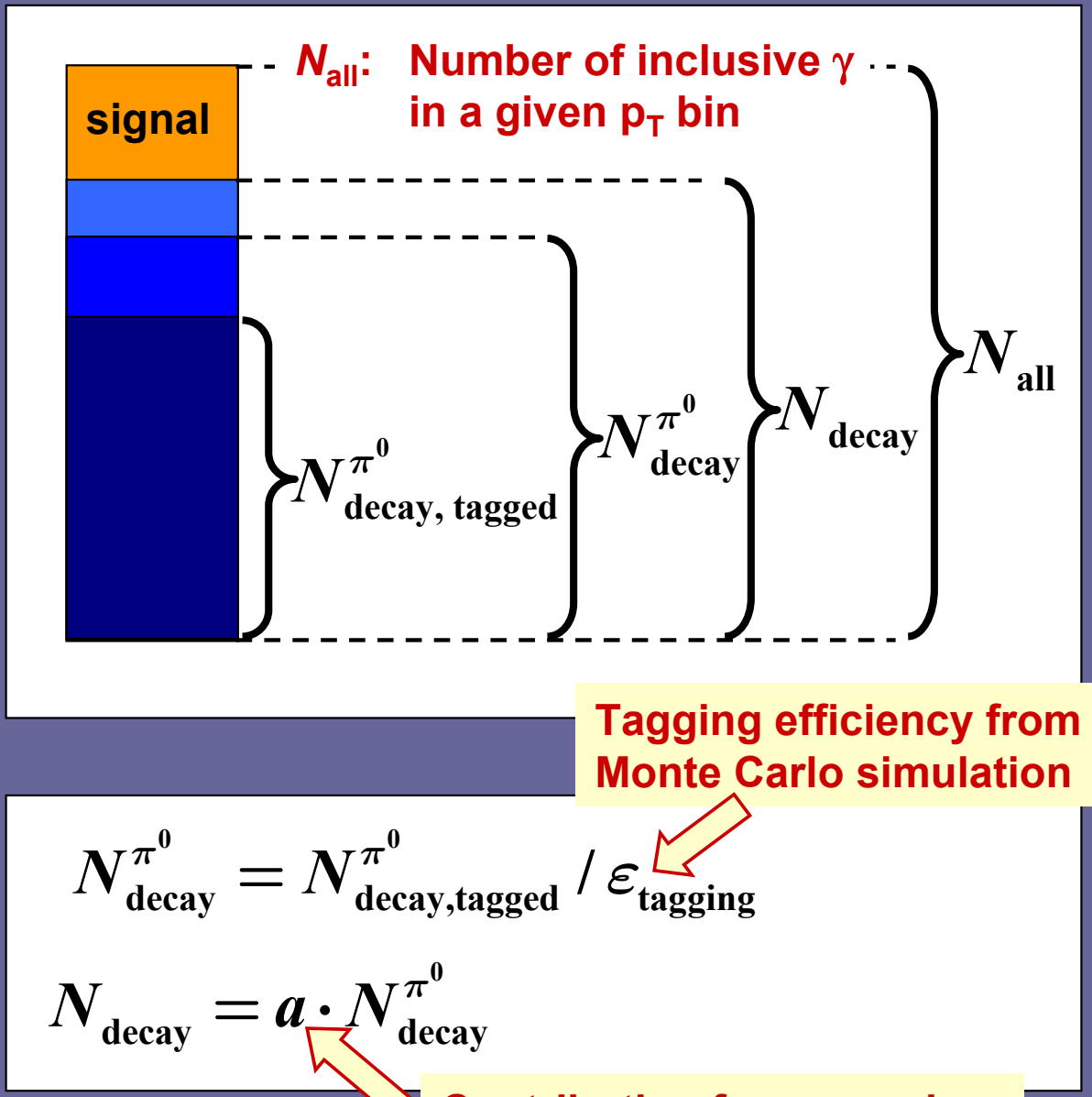


Pseudorapidity coverage : $|\eta| < 0.35$

- PbSc:
  - Highly segmented lead **scintillator** sampling calorimeter
  - Module size: 5.5 cm x 5.5 cm x 37 cm
- PbGl:
  - Highly segmented lead glass **Cherenkov** calorimeter
  - Module size: 4.0 cm x 4.0 cm x 40 cm
- Two technologies – very important for understanding systematic errors

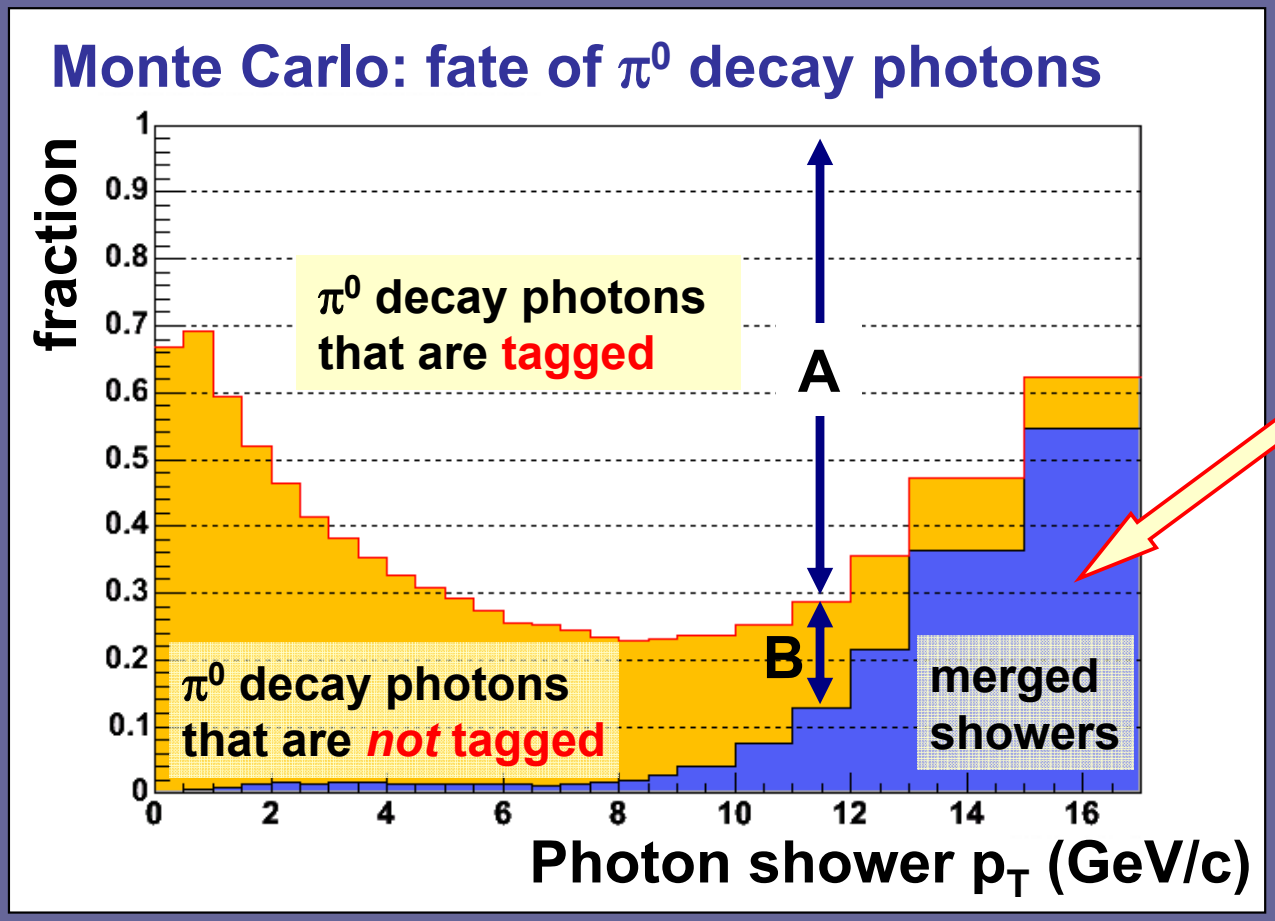
Analysis Procedure (I)

1. Start with all photons in a given p_T bin
2. π^0-Tagging:
   - Determine number of photons in this bin which form inv. mass in π^0 range with any other hit
   - Subtract combinatorial background
3. Correct for tagging efficiency and contribution from η, ω, η'
4. $N^{\gamma}_{\text{direct}} = N_{\text{all}} - N_{\text{decay}}$



Analysis Procedure (II)

- Efficiency for tagging π^0 decay photons determined with Monte Carlo calculation



To 100% removed by a cut on the shower width

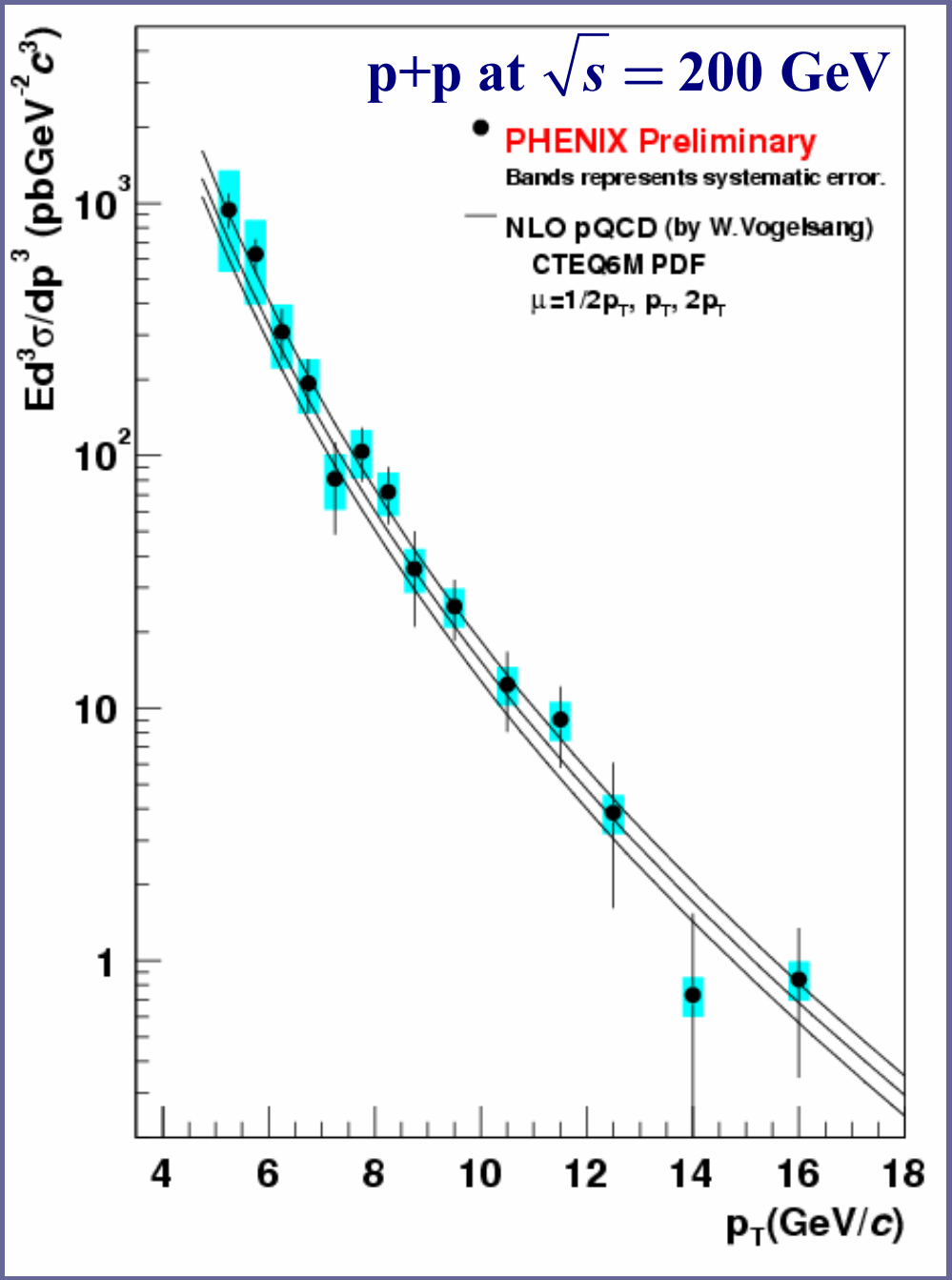
⇒ **Experimental background = A+B**

Tagging Efficiency:

$$\varepsilon_{\text{tagging}} = \frac{A}{A+B}$$

Shower merging of π^0 decay photons doesn't pose a problem!

Direct Photon Spectrum



- p+p direct photon data at highest energy world wide
- NLO pQCD (W. Vogelsang)
  - CTEQ6M PDF
  - GRV parton-to-photon fragmentation function
  - Uncertainty due to choice of unphysical scales: 20-30%

Good agreement between data and NLO pQCD

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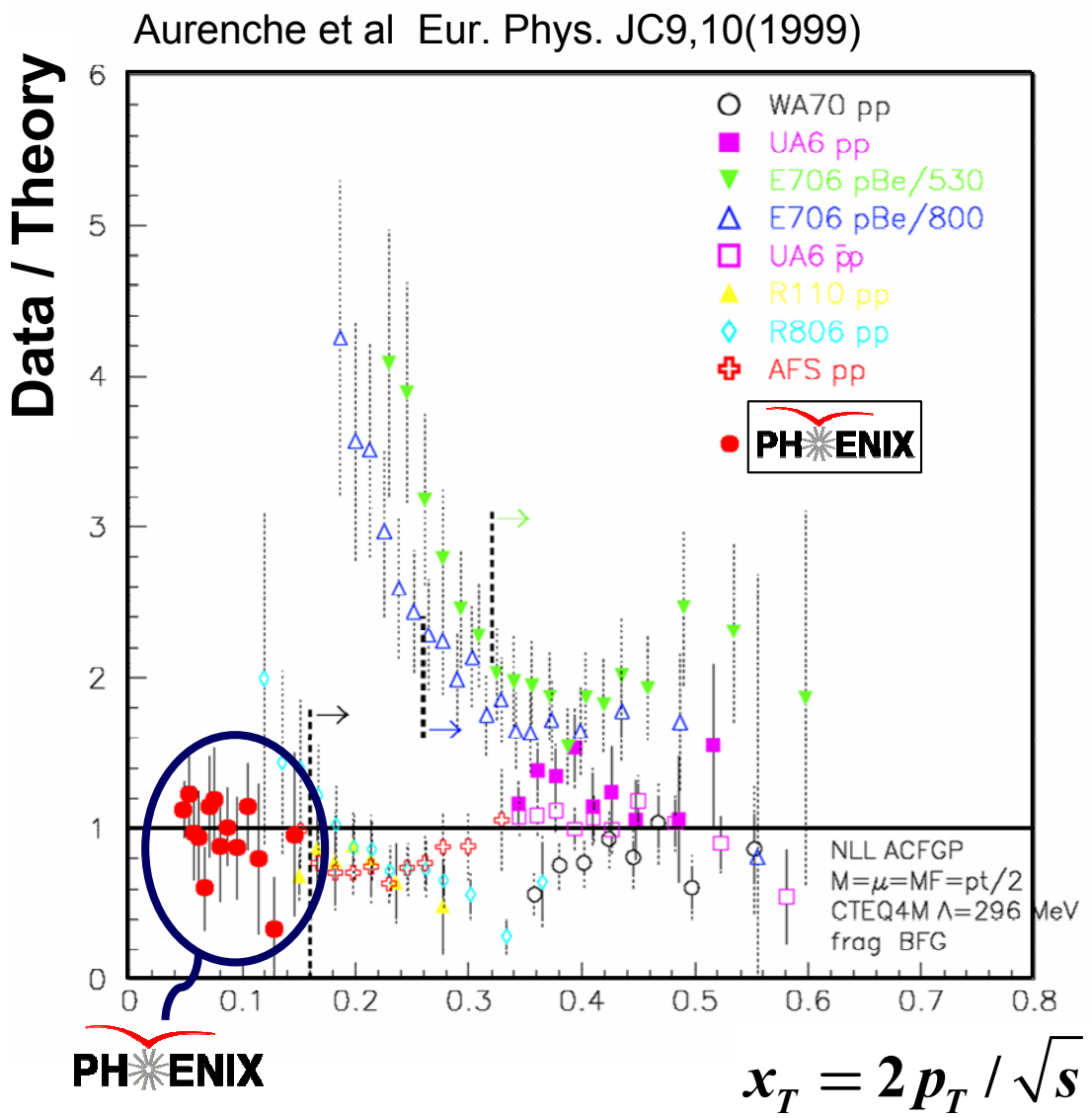
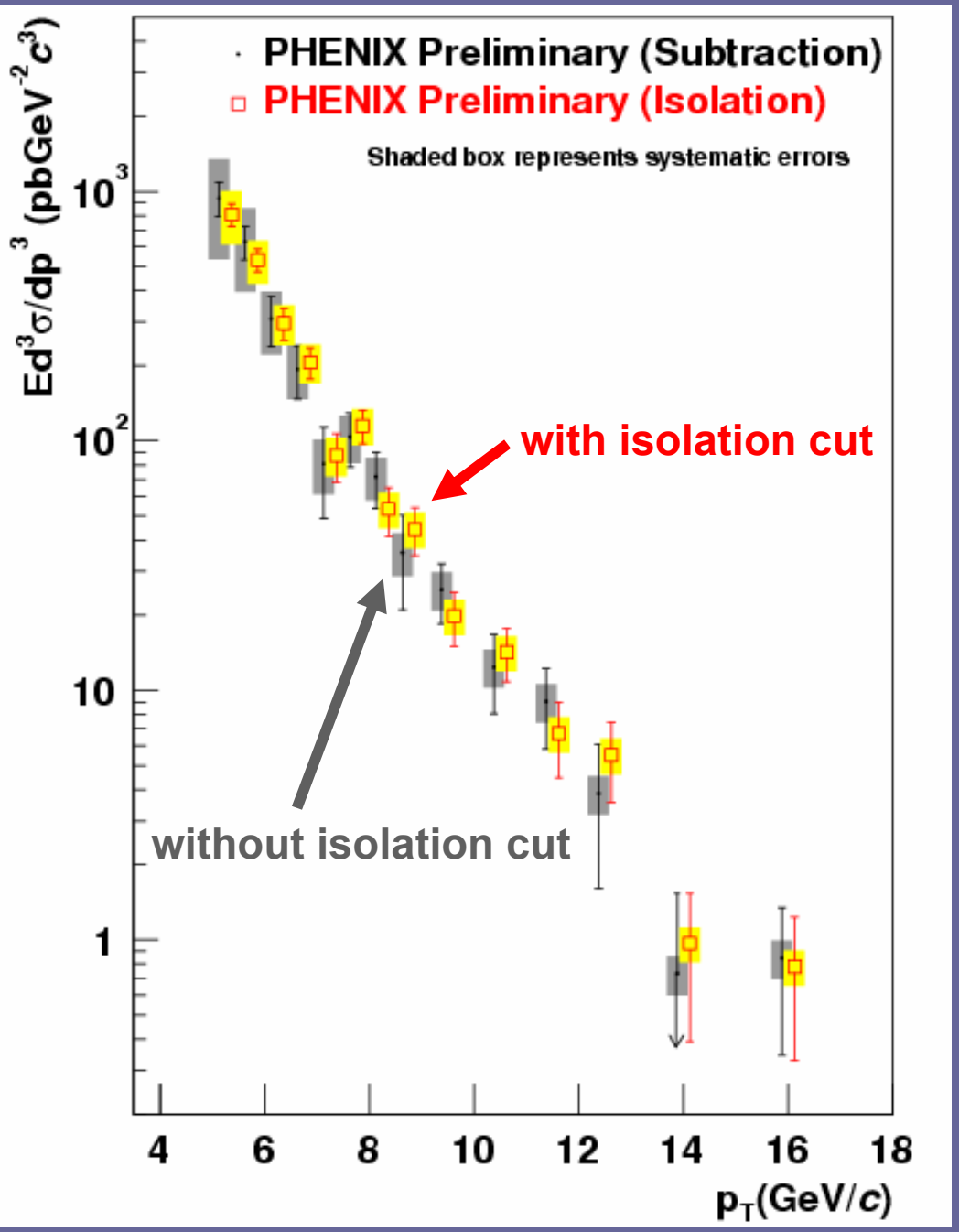
Data/Theory Comparison



Plot updated with PHENIX data: Monique Werlen, RHIC-AGS Users meeting, 2005

No need for additional k_T broadening in NLO pQCD description of p+p data at $\sqrt{s}$ = 200 GeV

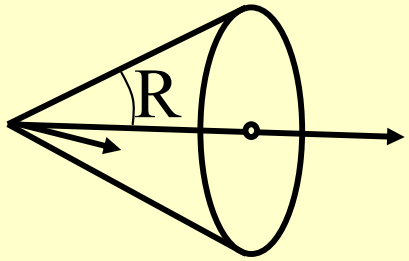
Isolation Cut



- Isolation cut:

$$R := \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

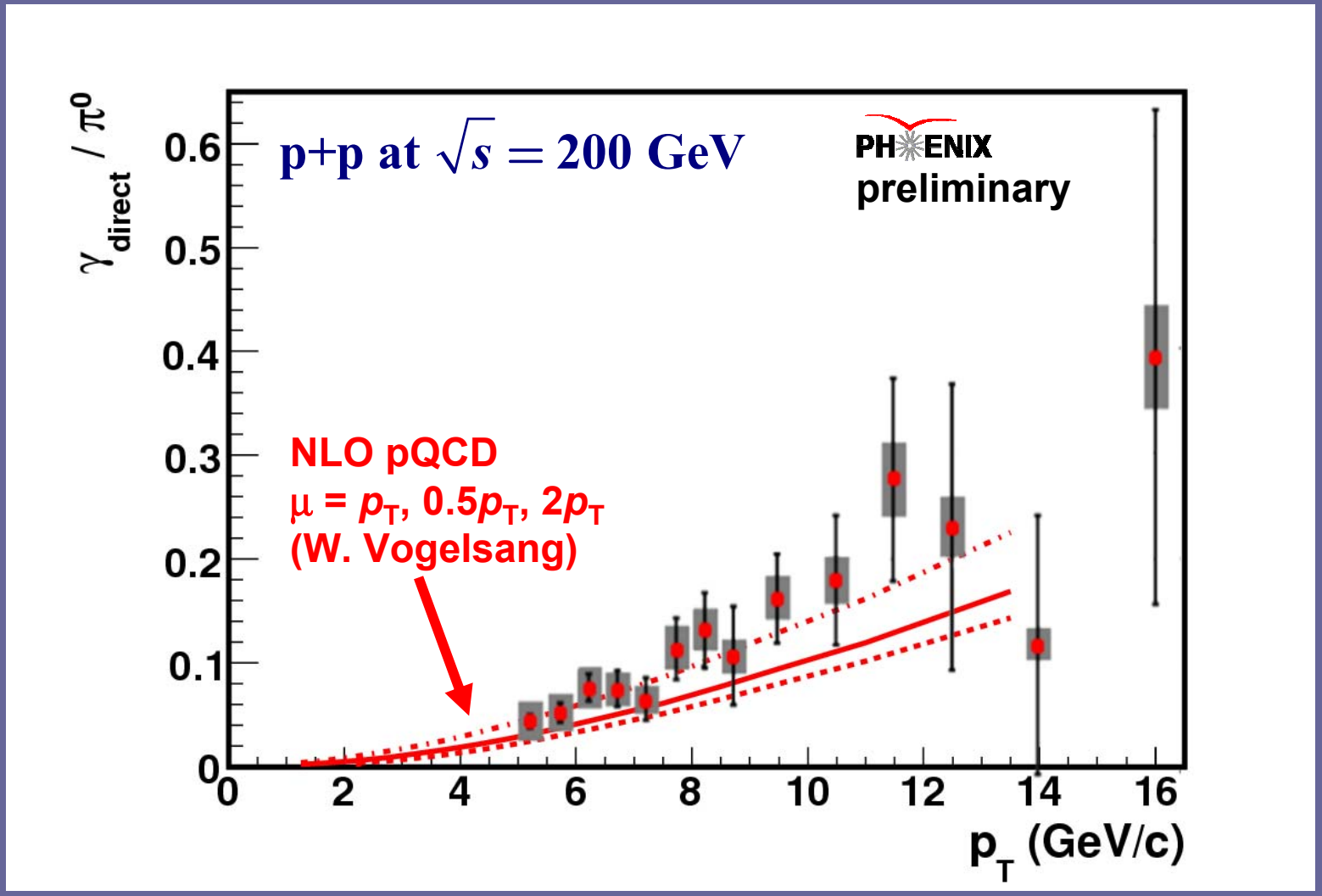
$$E_{sum}(R < 0.5) < E_\gamma \times 0.1$$



- No correction for isolation cut efficiency

No discernable difference in direct photon cross section with and without isolation cut

γ_{direct} / π^0 Ratio



PHENIX π^0 data:
Phys.Rev.Lett.91:241803,2003

γ_{direct} / π^0 data agree with pQCD expectation

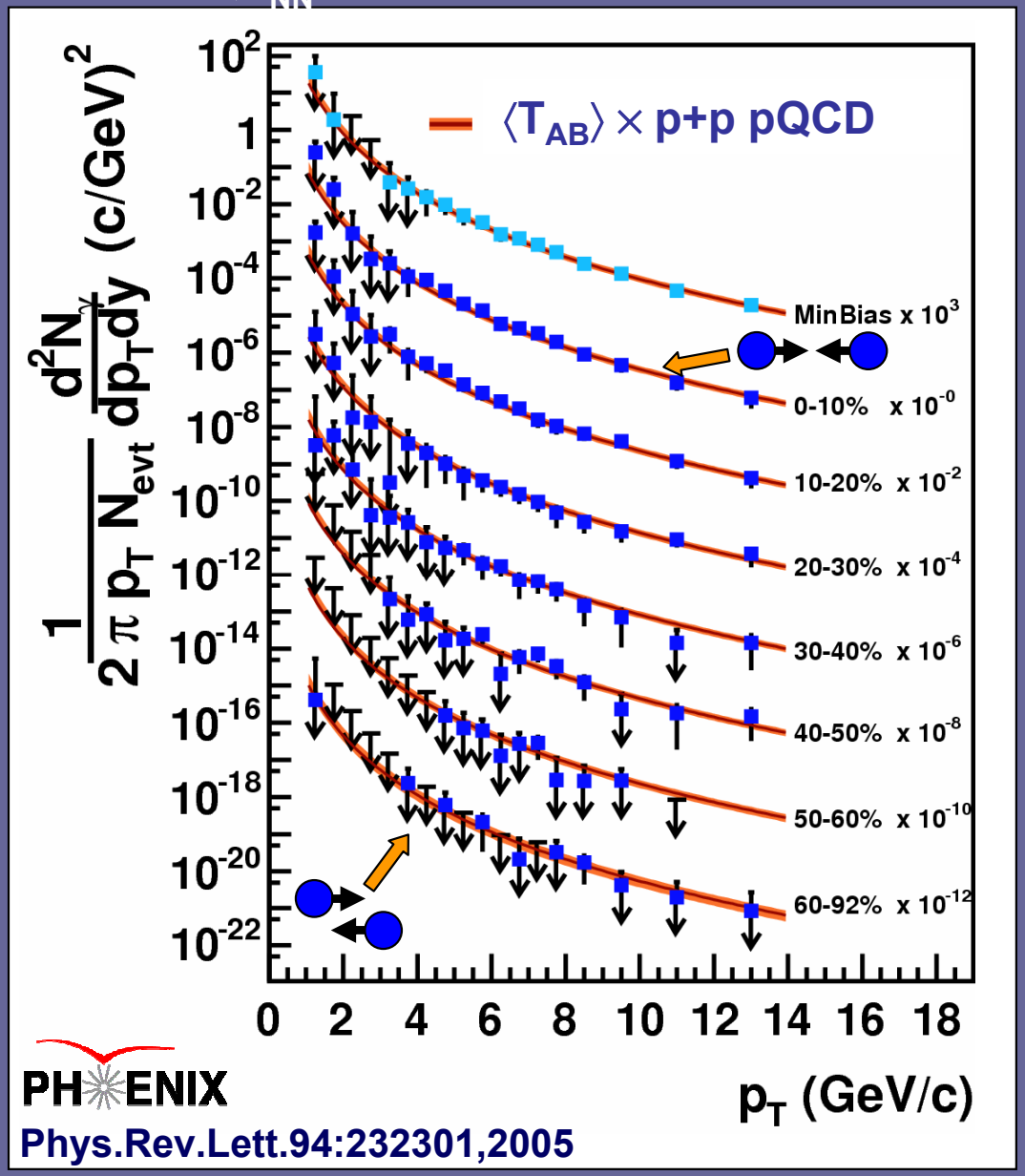
Direct Photons A+A Collisions – Why?

1. High p_T direct photons provide measure of parton luminosities in A+A collision
   - High-p_T direct photons produced in initial hard parton-parton scatterings
   - Photons leave the subsequently produced medium (**quark-gluon plasma!?**) unaltered

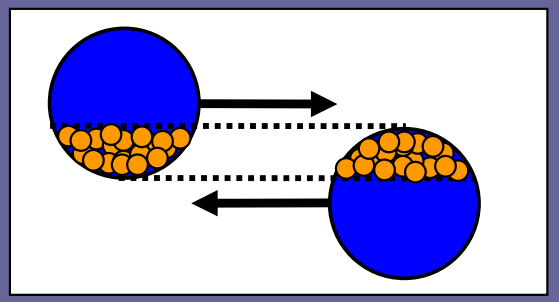
2. Low p_T thermal direct photons ($\sim 1 < p_T < \sim 3$ GeV/c) reflect the temperature of the quark-gluon plasma ($dN/dE \sim \exp(-E/T)$) (not part of this talk)

Direct Photons in Au+Au

Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

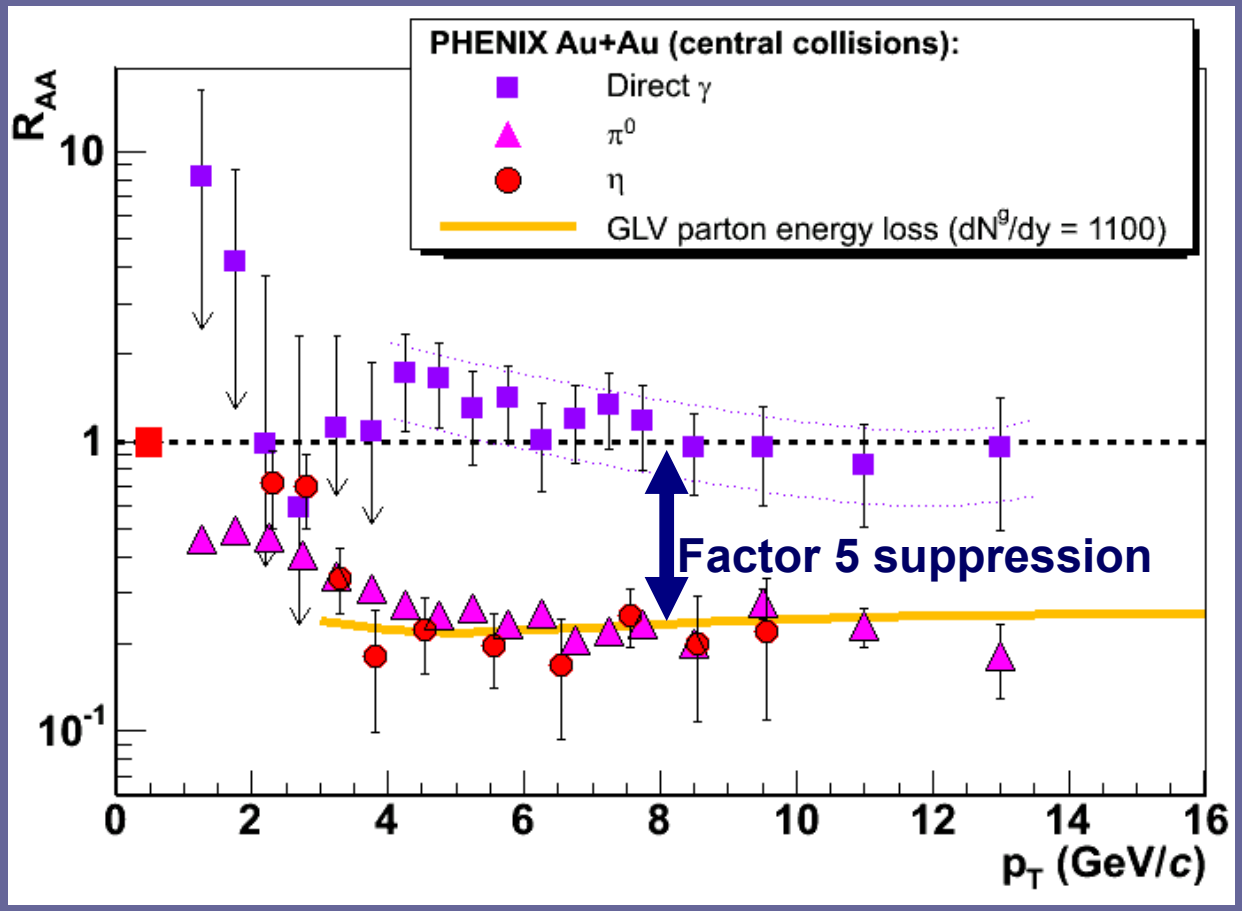


- Nuclear overlap function $\langle T_{AB} \rangle$
  - Measures increase of parton luminosity as function of impact parameter *b*
  - Calculated with a simple geometrical Glauber model

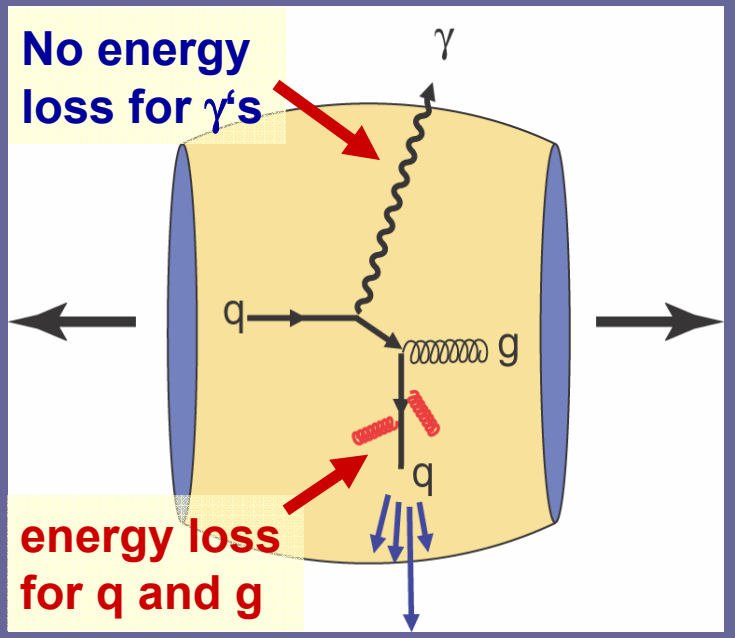


High-p_T direct photons scale with $\langle T_{AB} \rangle$

Nuclear Modification Factor R_{AB}



$$R_{AB} = \frac{\mathrm{d}N / \mathrm{d}p_T\big|_{\mathrm{A+B}}}{\langle T_{\mathrm{AB}} \rangle \times \mathrm{d}\sigma / \mathrm{d}p_{\mathrm{T}}\big|_{\mathrm{p+p}}}$$



Hadrons are suppressed while direct photons are not: Evidence for parton energy loss (as expected in the QGP)

Summary

- p+p collisions at $\sqrt{s}$ = 200 GeV
  - Direct photon production described by NLO pQCD
  - No need for strong initial state k_T broadening in pQCD description
- Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
  - High-p_T pions are suppressed relative to parton luminosity increase calculated from nuclear geometry (i.e. relative to $T_{AB} \times$ p+p)
  - Unlike pions high-p_T direct photons follow T_{AB} scaling
  - Thus, pion suppression is a final state effect, consistent with parton energy loss in a quark-gluon plasma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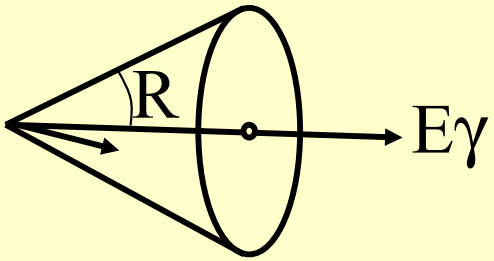
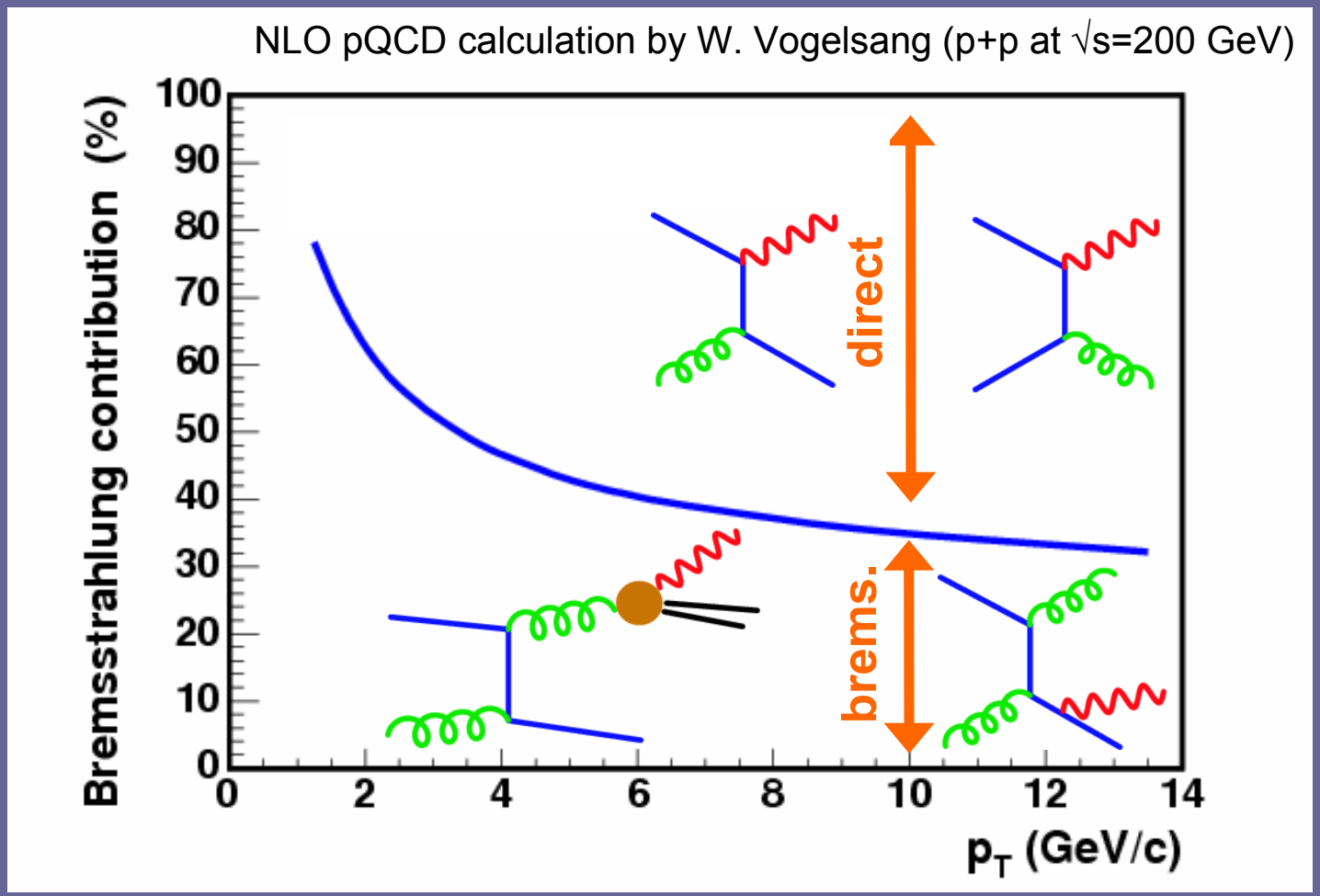
Backup

Isolation Cut (I)

Isolation cut $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$

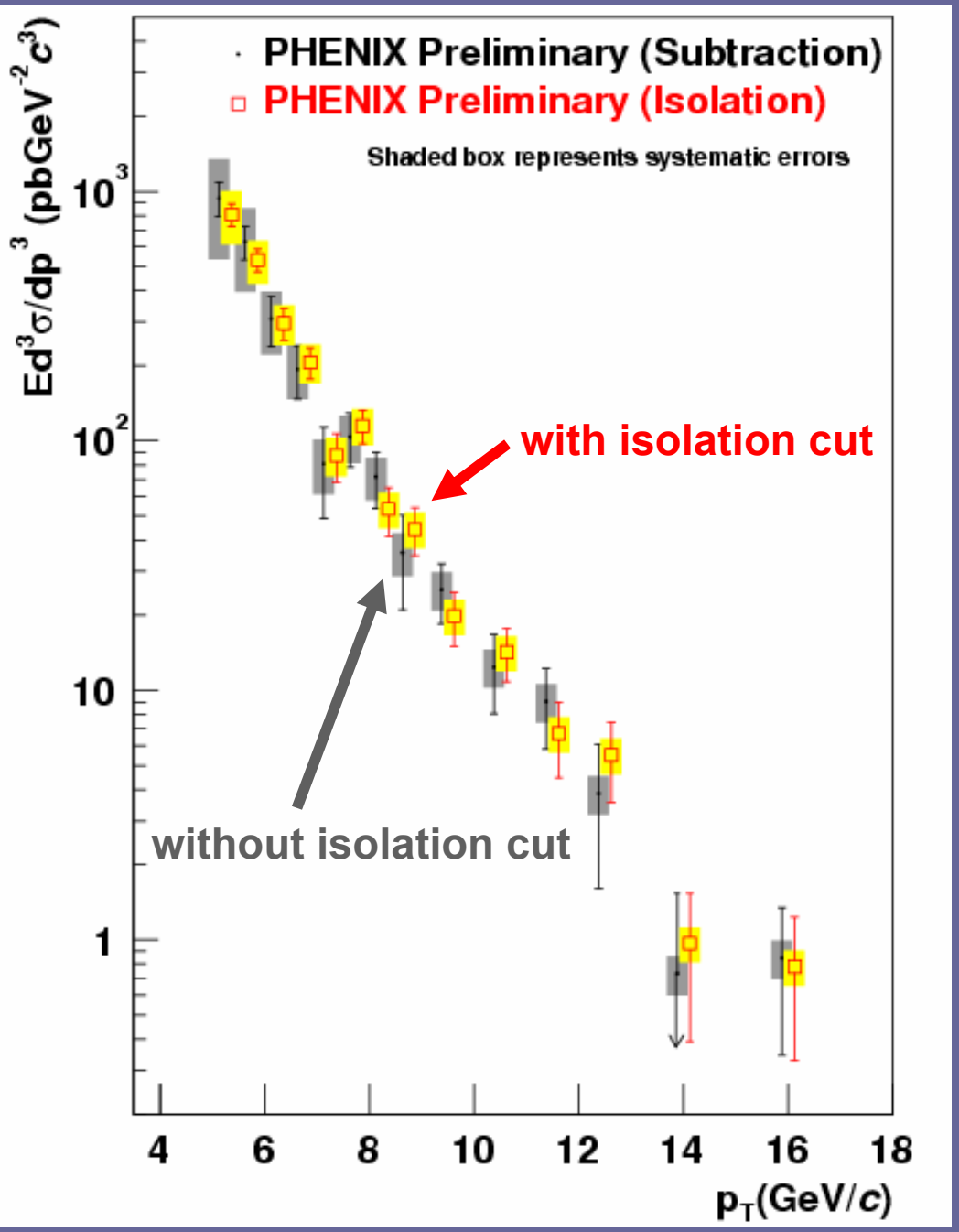
in this analysis $E_{sum}(R < 0.5) < E_\gamma \times 0.1$





- Isolation cut should remove contribution from **bremsstrahlung**
- Difficult to determine the efficiency of the isolation cut

Isolation Cut (II)



- No correction for isolation cut efficiency

No discernable difference in direct photon cross section with and without isolation cut

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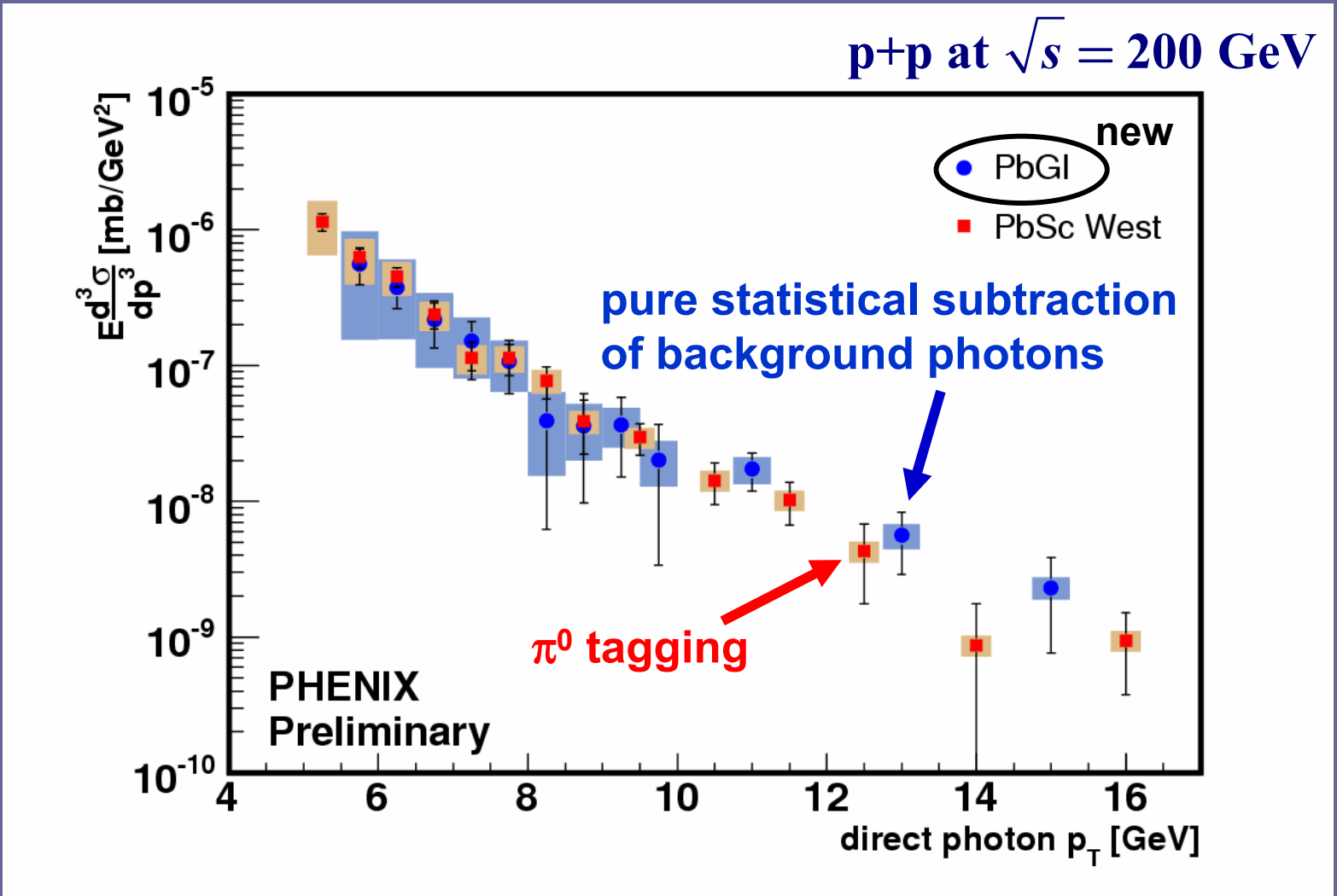
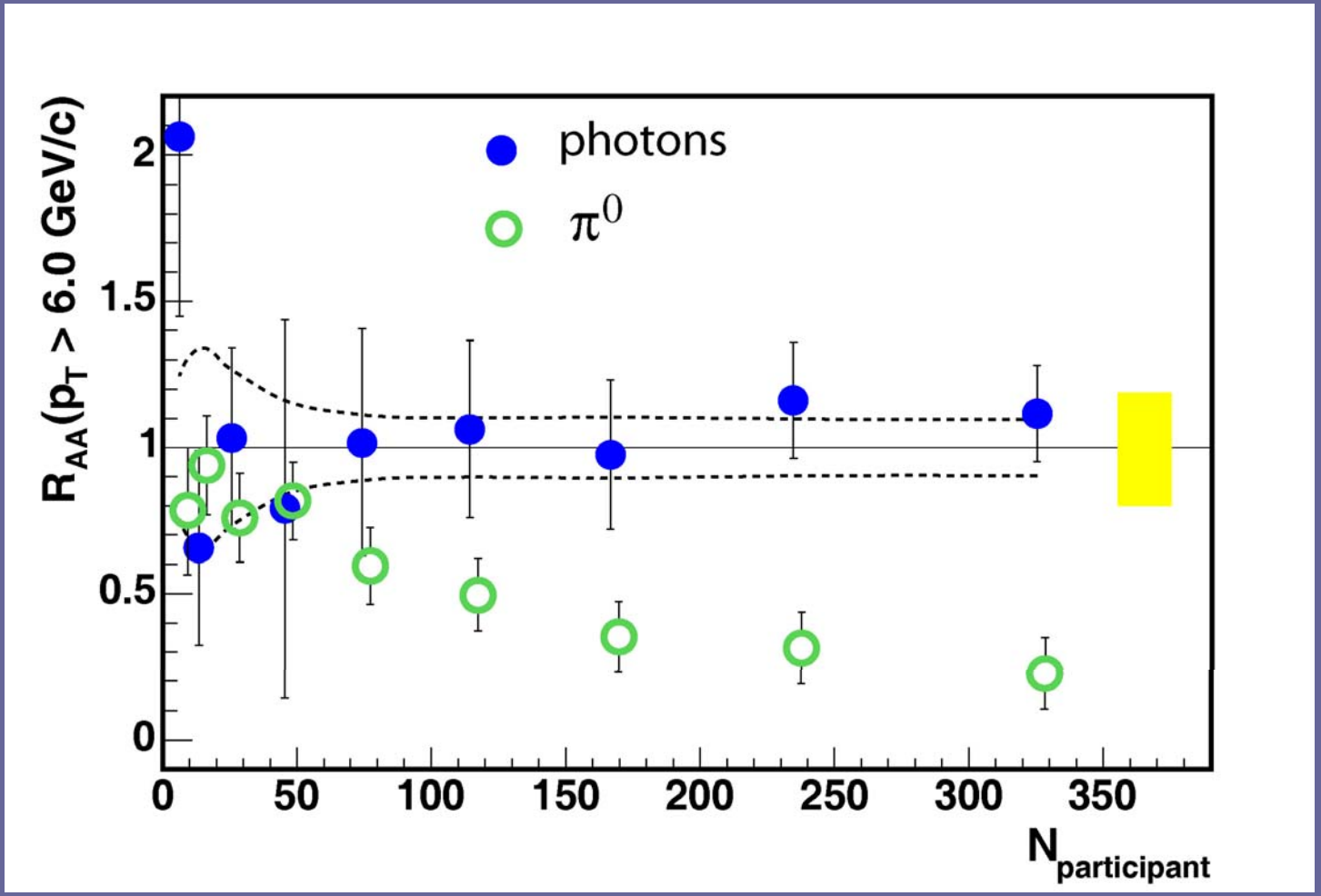
Direct Photon Spectra

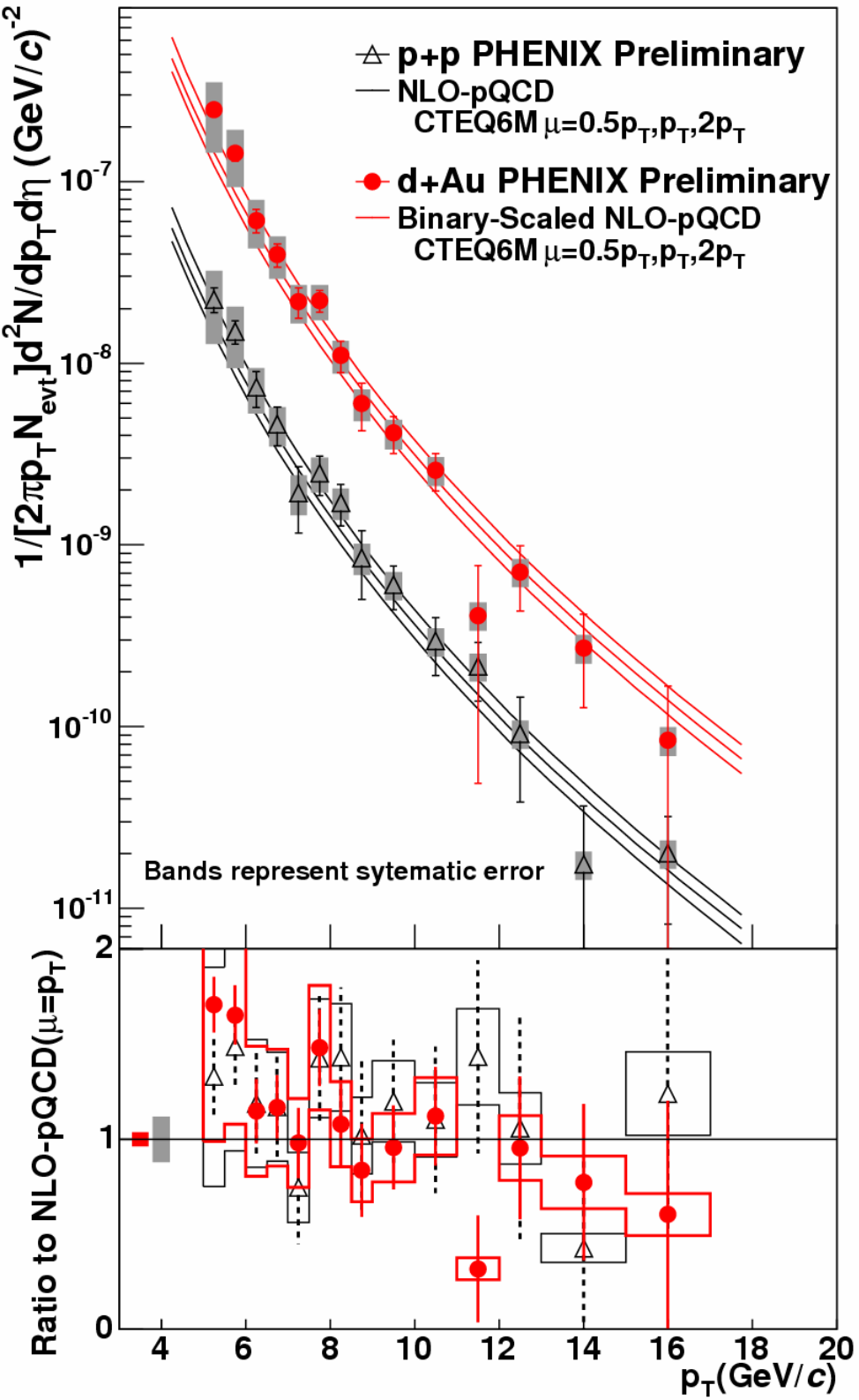


Good agreement between different detectors and methods

Centrality Dependence of R_{AB}



- T_{AB} scaling of direct photons for all centrality classes
- Pion suppression sets in for N_{part} greater ~50-75



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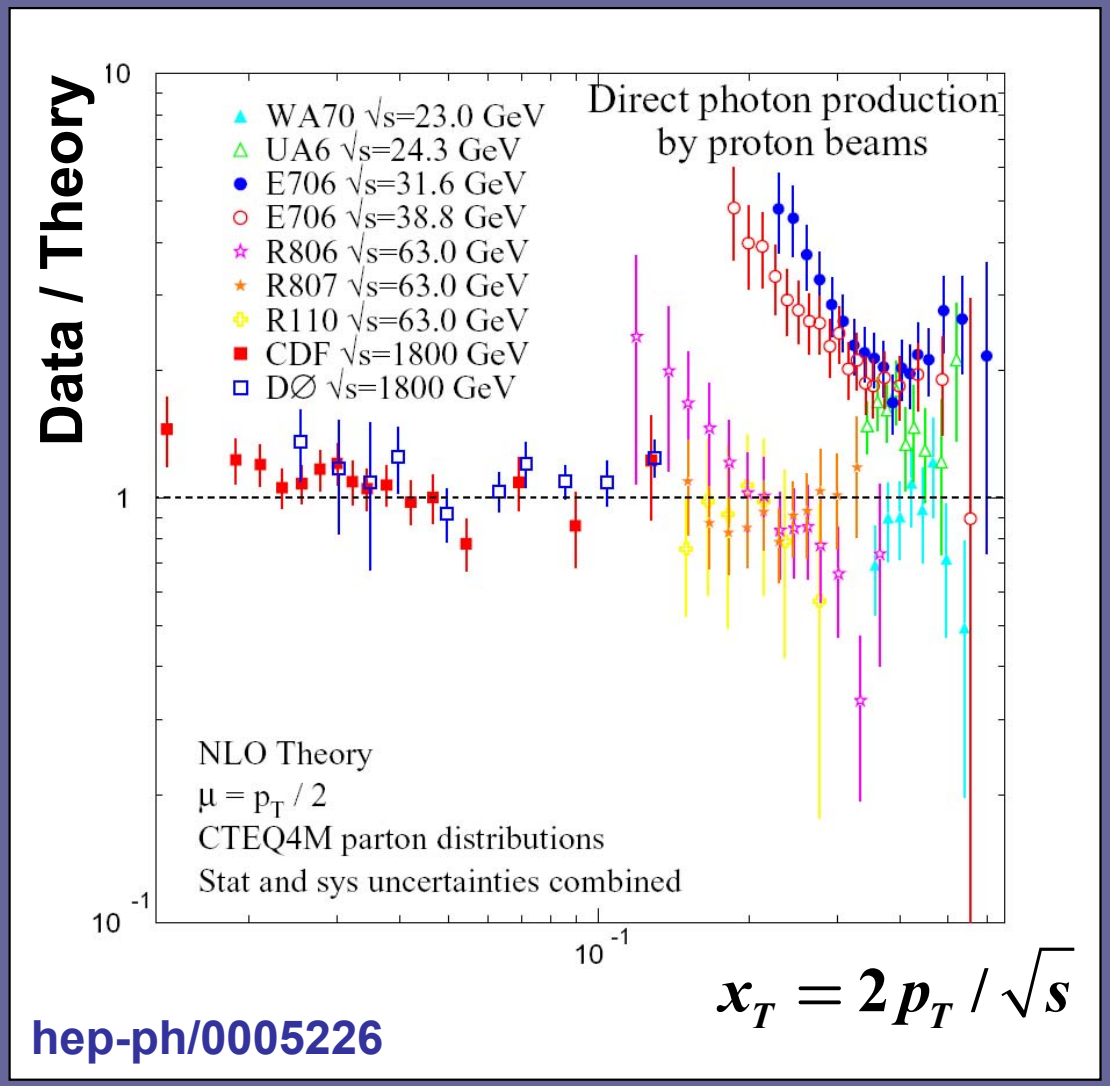
Systematic Errors

200 GeV p+p, tagging method:

	Lowest p_T 5-5.5 [GeV/c]	Highest p_T 15-17 [GeV/c]	
π^0 tagging efficiency	30%	5%	Point to point
Non π^0 contribution	27%	6%	
Photon acceptance and smearing	10%	10%	
Photon conversion effect	1%	1%	
Luminosity measurement	12%	12%	global
BBC trigger bias	3%	3%	
Total	43%	18%	

p+p($\bar{p}$) Direct Photon Data and pQCD – What's the Status?



hep-ph/0005226

- Decent agreement at large √s
- Substantial deviations between data and NLO pQCD at small √s
- Systematic pattern of deviation lead to speculations that transverse momentum (k_T) of initial partons prior to hard scattering needs to be taken into account …
- … or maybe there are just inconsistencies in the measured data?

Need new measurements to solve the puzzle